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An analysis of the U.S. Navy P-3C Orion service life extension program

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AN ANALYSIS OF THE U.S. NAVY P-3C ORION SERVICE LIFE EXTENSION PROGRAM

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September 2013

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AN ANALYSIS OF THE U.S. NAVY P-3C ORION SERVICE LIFE EXTENSION PROGRAM

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Submitted in partial fulfillment of the requirements for the degree of

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ABSTRACT

The P-3 service life extension program (SLEP) served to extend the P-3's capabilities. The P-3 fulfilled a wide breadth of mission sets, ranging from overland ground troops support to littoral surveillance to hunting submarines. Answering the demand for multi-mission capability, the 24-year-old P-3 entered a sustained readiness program (SRP), extending its airframe from its current 29-year service life to its limited fatigue life of 38 years. Unexpected findings, however, arose during SRP. The P-3s had so much corrosion that SRP contract could not sustain the 221 aircraft fleet. As such, the aircraft went through a service life assessment program (SLAP) to determine not only the severity of the corrosion problem, but also the structural life remaining on the airframe. In addition, SLAP offered corrective structural remedies if the aircraft were suitable for SLEP. SLAP results were promising: The airframe can be extended by another lifetime. With new wings and a fatigue life management program, the P-3 could safely execute its missions for an additional two decades, satisfying the constant demand. Five years into SLEP, however, many P-3s were grounded due to out-of-tolerance wing cracks, leaving a third of its fleet on the ramp. This thesis analyzes the challenges of SLEP.

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LIST OF ACRONYMS AND ABBREVIATIONS

AIP	ASuW Improvement Program
ASuW	antisurface warfare
ASW	antisubmarine warfare
BMUP	block modification upgrade program
BRAC	base realignment and closure
C4ISR	command, control, communication, computers, intelligence, surveillance and reconnaissance
CAPE	Cost Assessment and Program Evaluation
CBA	cost-benefit analysis
CBO	Congressional Budget Office
CF	Canadian Forces
CNO	Chief of Naval Operations
DAB	Defense Acquisition Board
DAG	Defense Acquisition Guidebook
DAU	Defense Acquisition University
DOD	Department of Defense
DODI	Department of Defense Instruction
DMSMS	diminishing manufacturing sources and material shortages
DMTS	digital magnetic tape system
FLE	fatigue-life expended
FLMP	fatigue life management program
FMC	full mission capable
FRCSE	Fleet Readiness Center Southeast
FSFT	full-scale fatigue test
GAO	Government Accountability Office
GPS	Global Positioning System
GWOT	global war on terrorism
IACS	integrated acoustic communication system
IOC	initial operational capability
IPS	integrated product support

IRDS	infrared detection set
JCIDS	Joint Capabilities Integration and Development System
KPP	key performance parameters
KSA	key support attributes
LRAACA	Long Range Air ASW Capable Aircraft
MAD	magnetic anomaly detection
MC	mission capable
MMA	multimission maritime aircraft
MOOTW	military operations other than war
NAS	naval air station
NAVAIR	Naval Air Systems Command
NMS	national military strategy
NPS	Naval Postgraduate School
OEF	Operation Enduring Freedom
OIF	Operation Iraqi Freedom
O&S	operating and support
OPTEMPO	operational tempo
OSD	Office of the Secretary of Defense
PPBE	Planning, Programming, Budgeting and Execution
RAAF	Royal Australian Air Force
RD&A	Research, Development and Acquisition
RFP	request for proposal
RNLF	Royal Netherlands Navy
SAR	search and rescue
SASP	single advanced signal processor
SLAM	stand-off land attack missile
SLAP	service life assessment program
SLEP	service life extension program
SRP	sustained readiness program
SRS	sonobuoy reference system
TMS	tactical mission software
VAMOSC	Visibility and Management of Operating and Support Costs

I. INTRODUCTION

Best value must be viewed from a broad perspective and is achieved by balancing the many competing interests in the system. The result is a system, which works better and costs less.

—Federal Acquisition Regulation 1.102-1(b)

This chapter begins with the origins of the P-3 Orion and the role it plays as a weapons system. Prior to the weapon system reaching the end of its service life, the Navy needs to decide whether to deactivate or to extend the service life of the system. Due to the fiscal budget environment and evolving national threat, the P-3 Orion went through service life extension program (SLEP). This research analyzes the P-3 management challenges, and as such, the framework of this research will be discussed prior to moving on to the next discussion point: The analysis structure.

A. BACKGROUND

1. P-3C Orion

The P-3 Orion built by Lockheed Martin served as a land-based, long-range anti-submarine warfare (ASW) patrol aircraft. The P-3 Sustainment Primer (n.d.) reported that in 1957, the Chief of Naval Operations (CNO) issued a requirement for an ASW patrol aircraft to include a short development period, low cost per aircraft, and a larger operational radius and longer endurance than the fielded P-2 Neptune. To meet the short development period and low-cost-per-aircraft requirements, Lockheed offered a variant of an existing commercial airliner, L-188A Electra, which had been in production since 1955. To meet the larger operational radius and longer endurance, Lockheed chose the same turboprop engines that were used on the C-130A Hercules. As a result, the P-3 Orion emerged with the capability to conduct high-speed transit to operations area and to have economical fuel consumption during low altitude, low airspeed ASW prosecution (Maritime Patrol & Reconnaissance Office, n.d., p. 3).

Figure 1. Clockwise Lockheed L-188A Electra (from Ed Coates Collection, n.d.), C-130A Hercules (from First In Flight, n.d.), and P-3A Orion (from *Wikimedia*, n.d.)

The P-3 Orion went through multiple production improvements. The P-3 Orion Research Group (2013) indicated that the P-3A arrived to the fleet in 1962, P-3B in 1965, and finally, P-3C in 1968. With each improvement, the P-3 Orion gained improved engines, enhanced fuselage structure, improved lethality packages and updated navigation and ASW suite. The last P-3C delivered to the U.S. fleet was in April 1990 (P-3 Orion Research Group, 2013, para. 6-8). The P-3 has remained a formidable force multiplier over its 52-year operational life span.

The P-3C ASW suite went through four major improvement or "Update" programs. According to Naval Historical Center (2000), Update I (UI) provided increased ASW computer memory and additional tactical displays. Update II (UII) added the infrared detection set (IRDS) for improved visual images, and sonobuoy reference system (SRS) that facilitated ASW prosecution through a software-generated reference field. Update II.5 (UII.5) added digital magnetic tape system (DMTS) to the ASW computer system and integrated acoustic communication system (IACS) to communicate

with friendly submarines. Finally, Update III (UIII) introduced single advanced signal processor (SASP) system that allowed programmable post-processing of acoustic data (Naval Historical Center, 2000, para. 7-8). Associated with these improvements were communication suites such as radios and data link, navigation units from enhanced inertial systems to Global Positioning System (GPS), and lethality package to include aircraft ability to carry Harpoon anti-ship missiles. These updates provided the P-3C capability to combat "modern submarines [that] posed a great threat not only to the survivability of warships and merchant vessels, but also to naval bases, ports, coastal installations and military and political-economic centers" (Vego, 2008, para. 3).

2. Deactivation and Replacement Aircraft Efforts

The P-3 Orion Research Group (2013) published that many P-3 Orion aircraft built in the early 1960s reached the end of their useful service life in the 1990s. Both the P-3A and P-3B have reached 30 years of continuous use, leaving the latest and most capable P-3C to continue the ASW mission. However, most P-3C aircraft had limited life remaining. Specifically, over half of the P-3Cs in the fleet built in the late 1960s would have reached the end of their useful service life by 2000 (P-3 Orion Research Group, 2013). Facing this reality, the Navy sought a replacement aircraft "with newer technology that could reduce support costs and provide enhanced antisubmarine warfare capabilities" to combat next generation of quieter submarines (Federation of American Scientists, 1998, para. 2).

The search for a replacement aircraft began in the mid-1980s. Federation of American Scientists (1998) reported that in 1986, the Office of the Secretary of Defense (OSD) approved the P-3G, a derivative of the P-3C. The P-3G would have "improved engines, reliability, maintainability, and survivability enhancements, vulnerability reductions, and advanced mission avionics to meet operational requirements" (Federation of American Scientists, 1998, para. 3). Moreover, the Navy desired competition in the development of the P-3 replacement to achieve a superior warfighting system, while driving down procurement costs. However, upon release of the draft request for proposal (RFP), only Lockheed indicated an interest in the P-3G program. Without competition,

the Navy opted not to award the contract. To encourage competition for the patrol aircraft acquisition, the Navy included the OSD's requirement to conduct patrol aircraft mission requirements determination study and expanded the scope to include commercial derivative aircraft in its next RFP. In 1988, the Navy selected Lockheed on the technically superior proposal with less risk on the technical approach over Boeing and McDonnell Douglas proposals for the P-3 replacement aircraft: P-7A Long Range Air ASW Capable Aircraft (LRAACA) (Federation of American Scientists, 1998).

The P-7A program ended before it even started. According to Vartabedian (1990), in 1989, eleven months after awarding the prototype development contract, Lockheed experienced schedule and design problems resulting in a $300M cost overrun. In 1990, unable to resolve contract issues with Lockheed, the Navy terminated-for-default the developmental contract due to Lockheed's "inability and/or unwillingness to meet other requirements of the contract" (Vartabedian, 1990, para. 1). Ambrose (2003) researched and found that by the end of 1990, the Defense Acquisition Board (DAB) officially cancelled the P-7A LRAACA program. Without a replacement aircraft for the aging P-3C, the Navy continued its efforts by proposing the P-3H program and later, re-submitting the P-3G associated with the Korean P-3C procurement. With each effort for a replacement aircraft, Congress denied any funding due to reduced defense spending and the perceived collapse of the former Soviet Union's submarine fleet (Ambrose, 2003).

3. Sustained Readiness Program

The future looked bleak for the P-3 after the Cold War. With the changing world order, the U.S. political climate shifted to domestic economy, demanding a military reduction. According to Principi (2005):

> By 1988, the Defense budget had declined for three straight years and was predicted to decline further [requiring that] scarce DOD resources would be devoted to the most pressing operational and investment needs rather than maintaining unneeded property, facilities, or overhead. (311)

This shift in DOD resources resulted in a series of Defense Base Realignment and Closure (BRAC) Commissions, closing two naval air stations (NAS) that supported P-3 squadrons (Defense BRAC Commission, 1991, 1993). Furthermore, "The Navy's

Maritime Patrol (VP) community [restructured] to meet military drawdown and downsizing objectives as part of the Defense Base Realignment and Closure initiative" (VP-30 Public Affairs, 1993, p. 5). This BRAC initiative and the Navy's budgetary constraints contributed to the disestablishment of 12 of 24 active P-3 squadrons (Polmar, 1993, p. 377). Not only the number of squadrons were decommissioned, but also the number of P-3 aircraft. The P-3 Orion Research Group (2013) illustrated that both P-3A and P-3B had reached their operational service life, mandating the retirement of these aircraft in 1990 and 1994, respectively. Only the P-3C variant remained in the active inventory with an average age of over 20 years (P-3 Orion Research Group, 2013). Finally, the national military strategy (NMS) shifted from worldwide containment to regional defense strategy, limiting P-3 area of operations (Cheney, 1993, p. 8). The days of P-3 aircraft appeared to be numbered.

The 1990–1991 Gulf War reconnaissance requirements led to expansion of the P-3 mission to include overland surveillance operations. Cooper (2008) reported that with its ability to remain on scene for an extended period of time, the P-3 provided over-the-horizon targeting solution, monitored troop activities and confirmed battle assessment on the ground. The P-3 proved to be a useful asset in the land surveillance mission. From this point forward, P-3s have been involved in military operations other than war (MOOTW), from supporting ground forces to protecting the U.S. embassy in Liberia, to monitoring street operations in Somalia, to tracking refugees for relief efforts in Rwanda (Cooper, 2008). The P-3s became a high-demand platform for both overland and oversea missions.

Executing overland missions required mission systems capabilities different from those needed for ASW. According to Erwin (2000), in 1994, the Navy awarded the contract to Lockheed Martin for the Anti-Surface Warfare Improvement Program (AIP). AIP retrofitted P-3C UIII with enhanced sensors such as advanced imaging radar, and electro-optic sensors. It provided additional strike capability to include configurations for stand-off land attack missile (SLAM) and Maverick missiles as well as survivability enhancements that provided chaff and flares. Lastly, AIP added command, control, communications, computers, intelligence, surveillance, and reconnaissance (C4ISR)

capabilities, leveraging improved satellite communications for near-real-time connectivity of surveillance and reconnaissance data with battle group and national command decision-makers (Erwin, 2000). The capabilities provided have enabled the aircraft to be used extensively in major U.S. combined forces operations, including those in Iraq, Afghanistan, Kosovo, Bosnia, and others associated with the global war on terrorism (GWOT) (Deagel, 2014).

P-3C aircraft have expanded their oversea missions. P-3C UIII have performed ASW, mining, search and rescue (SAR), drug interdiction, and exclusive economic zone protection (Naval Air Systems Command, 2009). With AIP upgrades, P-3 has become a multi-mission aircraft, capable of executing missions in the open ocean to the littorals to overland. Deagel (2014) reported that 65 P-3C UIII originally received the AIP kits. Being capable of executing a wide range of missions, theater and fleet commanders required 40 P-3Cs continuously forward-deployed. Five P-3C UII.5 and 3 P-3C UII were later retrofitted to AIP configuration in order to keep up with the demand. Furthermore, 25 P-3C UII and II.5 went through the block modification upgrade program (BMUP) to supplement the UIII inventory and fulfill UIII missions. BMUP aircraft leveraged commercial-off-the-shelf technology to modernize dated systems to UIII capability. The Navy took advantage of any remaining service life available airframe to meet increasing operational demands (Deagel, 2014).

Service life issues remained for the aircraft. With both P-3A and P-3B decommissioned, the most modern P-3C UIII continued to execute the maritime patrol missions with an aircraft average age of over 20 years (P-3 Orion Research Group, 2013). Some UIII were retrofitted with AIP. Some UII and II.5 aircraft were modernized to UIII through BMUP (Deagel, 2014). The Navy stretched the aircraft as far as it could and faced the diminishing service life of the aircraft. To address this limiting factor, the Navy implemented the sustained readiness program (SRP) (Erwin, 2000).

Erwin (2000) reported that SRP addressed aircraft materiel condition and supportability issues of the P-3. The goal of SRP was to "extend the service life of the aircraft from 29.5 years to the fatigue life of approximately 38 years" (U.S. Navy, 1999, P-3C Orion, para. 5). SRP "involved replacing, upgrading, and refurbishing the fuselage,

wings, spar caps, flaps and empennage, replacing control cables and portions of the avionics and electrical wiring" (Erwin, 2000, para. 8). With a solution in sight, the Navy awarded a fixed price contract to Raytheon to work on 32 aircraft in 1994. Raytheon, however, discovered more corrosion-related damage than expected. Only 13 of 32 aircraft were delivered based on the established cost on the contract (Erwin, 2000).

4. P-3C Service Life Extension Program

SRP was designed to sustain the current P-3 inventory; however, with the discovery of extensive corrosion damage accumulated over the decades, the Navy launched a service life assessment program (SLAP) in 1996 (Erwin, 2000). Phan (2003) asserted that SLAP re-assessed the airframe and materiel condition, and full-scale fatigue test (FSFT) determined that not only the fatigue life of the aircraft, but also the "structural inspections, modifications, replacements and redesigns necessary to sustain the P-3 fleet to at least the year 2015" (Phan, 2003, p. 2). The U.S. Navy and its Foreign Military Sales partners, specifically the Canadian Forces (CF), Royal Australian Air Force (RAAF) and Royal Netherlands Navy (RNLN), found the necessary materials, designs and processes needed for the P-3's SLEP, extending the airframe by one lifetime of 24,000 total hours (Phan, 2003; Erwin, 2000). In 2002, the Navy awarded the contract to Lockheed Martin to SLEP 221 P-3 aircraft (Global Security, 2011).

SLEP, however, did not resolve the airframe problem. According to Global Security (2011):

> Following structural tests of the P-3C fleet, engineering evaluations determined airframes had less life in them than expected. Chief of Naval Operations directed the Navy in August 2003 to quickly reduce its fleet of 228 land-based surveillance aircraft to 150. (para. 51)

To make matters worse, Warwick (2007) reported that in December 2007, the Navy grounded 39 of its 161 P-3 for structural fatigue concerns, and of the 39 aircraft grounded, ten were forward deployed. The lower portion of the outer wing called Zone 5 showed cracks during an ongoing fatigue-life analysis and inspection of the airframes (Warwick, 2007). Further inspections grounded ten more aircraft in 2009 and others in between 2007 and 2009 (Trimble, 2010). How did SLAP miss these Zone 5 cracks?

Lockheed had performed fatigue life "assessment in 2000 based on a software algorithm developed in the 1980s" (Trimble, 2010). *Defense Industry Daily* (2013) reported that SLAP assessed that the fatigue life was beyond the algorithm, predicting serious failures. The P-3 fleet was beyond 100% fatigue life expended (FLE), a metric that the Navy used to retire aircraft. Management beyond this point required the Navy to implement a fatigue-life management program (FLMP) to inspect, track and update each aircraft status every 6 months for safety. Cracks were discovered during one the periodic inspections initiated by FLMP (*Defense Industry Daily*, 2013). Furthermore, Warwick (2007) reported, "NAVAIR says the affected area responsible for the latest grounded [aircraft] is not covered by any existing repair program" (Warwick, 2007, para. 4). As a consequence, grounding so many aircraft right after SLAP, which failed to address Zone 5, affected P-3 operational availability to fulfill its mission requirements. To return the aircraft back to the fleet as quickly as possible, *Defense Industry Daily* (2011) published that the Navy leveraged its depot maintenance, Fleet Readiness Center Southeast (FRCSE), and contracted Lockheed Martin, L-3 Communications and BAE Systems Applied Technologies, Inc. to repair Zone 5. In addition, Zone 5 repairs were expected to extend the airframe for 5,000 hours or 8 to 10 years until the Boeing P-8A Poseidon completely replace the P-3 Orion by 2019 (*Defense Industry Daily*, 2011).

5. Summary

For the past 52 years, the P-3 Orion has been in the fight. It has fulfilled the ASW mission against the Soviet Union's submarine force since the 1960s to today's submarine regional and global threat (NAVAIR, 2009). By the turn of the century, it adopted ASuW supporting littoral missions and overland combined forces operations in support of GWOT. Yet at the same time, the aircraft needed service life longevity due to an aging airframe. With no replacement aircraft after 20 years of service, corrosion conquered SRP impacting the ability to extend its service life from 29.5 to 38 years (Erwin, 2000). SLEP was to address the corrosion problem in addition to extending its service life by one lifetime; however, during SLAP, it had not discovered Zone 5 cracks, resulting in the grounding of an already weathered P-3C fleet. Despite these challenges,

the P-3 is scheduled to remain in the Naval inventory until 2019 when it will be completely replaced by the P-8 Poseidon (*Defense Industry Daily*, 2013).

B. PROBLEM STATEMENT

Lessons learned from P-3 Orion highlight the need for better planning. Interim Department of Defense Instruction (DoDI) 5000.02 (2013) states, "The sustainment key performance parameter (Availability) is as critical to a program's success as cost, schedule, and performance" (p. 113). Sustainment metrics such as materiel reliability, operating and support cost, mean down time and other metrics support materiel availability. Furthermore, stable Capability Requirements and funding are fundamental to successful program execution. Analyzing the P-3 sustainment program against the operation of the Defense Acquisition System (DAS) guidelines may shed light on its effectiveness.

Today's programs may learn from the lessons in the past. The aged P-3 Orion will be replaced by the P-8 Poseidon. Fifty-two years ago, the P-3A became operational in April 1962 (P-3 Orion Research Group, 2013). In November 2013, the P-8A achieved its initial operational capability (IOC) and is scheduled to reach full operational capability by 2018 (NAVAIR, 2014). While both aircraft share a common mission, they are very different airframes. One platform's future is known, and the other is yet to be determined. Perhaps the P-8 program could glean important sustainment and operational milestones from the P-3's history such as fulfilling capability gaps against future threats and extending its service life during lean budget environments.

C. RESEARCH OBJECTIVES

Research objectives are threefold on the P-3 Orion: review sustainment challenges, delve into SLEP considerations, and analyze the outcome. Sustaining a program for over 50 years requires intricate planning and scrupulous resource management. Despite due diligence, risk will always be a factor and is likely to increase over time. This project will analyze the cost, schedule and performance risks and the management of these risks.

SLEP offers additional time on the weapon system at a fraction of the cost of a replacement system. SLEP offered one more airframe lifetime to the already aged P-3. That promise is worth looking into. Overarching policies will be reviewed to determine if SLEP is a preferred method over acquisition of new aircraft. The results may present an opportunity to skip an entire generation prior to funding replacement aircraft.

Replacement aircraft management should not make the same sustainment mistakes as its predecessors. Lessons learned are invaluable in saving time, effort and cost. Perhaps this new generation of acquisition aircraft can glean lessons learned from its predecessor, which has been in the service for more than a half-century.

D. RESEARCH QUESTIONS

Research questions for the analysis of the P-3 Orion SLEP are as follows:

1. Did the Navy manage P-3 sustainment effectively?
2. Does DOD provide sufficient guidance for service life extension?
3. Should policy change to promote service life extension as cost savings?
4. How can other programs glean from the lessons of the P-3?

Question 1 looks at P-3 sustainment to draw any trends on cost and performance. Question 2 reviews DOD's guidance on SLEP and the sustainment goals that the P-3 should attain. Question 3 assesses the DOD's policies from Question 2 based on the success or challenges found with P-3 sustainment. Question 4 seeks to provide lessons learned from the P-3 platform that can be applied in other programs, minimizing or avoiding the repetition of any costly mistakes.

E. PURPOSE/BENEFIT

The purpose of this research is to gain insight on the P-3C Orion weapon system after undergoing SLEP. The P-3 program has experienced successes and challenges in keeping a 50-year old aircraft operationally available. As such, the benefits are the lessons learned gleaned from the analysis of P-3 sustainment after service life extension and the guidance in policies and directives on SLEP. Furthermore, the advantages and disadvantages can be identified, resulting in recommendations for future studies.

F. SCOPE/METHODOLOGY

This research focused on the SLEP decision and the outcomes of that decision. In Chapter II, the analysis structure reviewed current guidance polices on sustainment practices that influenced the SLEP decision. While the policy guidance during the inception of the P-3 program has changed as compared to today's policies, the need for programs to meet capability requirements, to be operationally available, and to be cost effective during the program's service life has remained applicable. In essence, all programs were required to adhere to best practices, remaining timeless in nature. Interim DoDI 5000.02, Defense Acquisition Guidebook (DAG), past Naval Postgraduate School (NPS) and other institution theses, Government Accountability Office reports, Defense Acquisition University (DAU) acquisition community connection, and RAND publications provided guidance on sustainment and SLEP decision.

Chapter III summarized the data and analysis of P-3 SLEP. Program review encompassed two decades worth of operating and support cost data from the Navy's Visibility and Management of Operating and Support Costs (VAMOSC). Utilization rate, in addition, contributed to the data as the Government Accountability Office (GAO) reported on the military's mission readiness. Using this data, the analysis revealed the trends in cost and mission capable rates. The cost analysis focused narrowly on maintenance and modernization cost, highlighting the needed efforts on an aging platform. P-3 mission capable rates provided a glimpse into its operational availability.

Findings in Chapter IV evaluated the P-3 SLEP. First, the SLEP decision was reviewed on a basis of cost. RAND's study on SLEP offered insight into cost analysis. Secondly, understanding the Navy's process on aircraft structural-life determination contributed to the evaluation found in RAND's study of the Navy's structural-life management approach. From a basis of these evaluations, findings of the P-3 SLEP ensued. Conclusions and recommendation followed in Chapter V.

G. THESIS STATEMENT

Balancing cost, schedule and performance is the basic tenet of defense acquisition. DOD policies and best practices guide decisions to achieve a weapon system

that not only fulfills the desired capability, but also falls within the cost and schedule constraints. Once the system is fielded, DOD enjoys the capability that the weapon system provides to include its predictable sustainment cost and operational availability. However, that predictability ends once the weapon system reaches the end of its service life.

Beyond a weapon system's nominal service life, its operational availability is likely more difficult to maintain and average cost of maintenance typically goes up. Maintenance will occur more often in order to keep the system operational. Furthermore, not only the structural-life of the airframe degrades, but also the mission systems onboard the aircraft suffer due to obsolescence and diminishing sources. As replacement technology and processes evolve, newer components become cheaper to procure and support as compared to sustaining older technology. As such, periodic modernization efforts are planned within the system's life cycle.

The thesis statement is therefore: Understanding that the sustainment costs will increase as a system operates beyond its normal service life, does SLEP offer cost savings?

H. REPORT ORGANIZATION

This report reviews the P-3 aircraft after undergoing SLEP. Chapter I provides a brief history on the P-3 aircraft followed by the problem statement, research objectives and thesis. Chapter II provides the analysis structure, reviewing DOD's process and policy to fund systems as well as sustainment expectations. Chapter III gleans P-3 operating and support (O&S) cost for the past two decades, the mission capable rates prior to and post-SLEP, and GAO reports on P-3. Chapter 4 data analysis and findings are followed by Chapter 5 conclusion and recommendations.

I. SUMMARY

This chapter provides a brief history of the P-3 Orion aircraft, which has been in the Naval arsenal for over 50 years. It follows with the problem statement on cost savings to SLEP the aircraft. Research objectives lay the foundation of this technical

report to include the research questions, purpose and benefit and thesis statement. The report organization provides the discussion points by chapter.

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II. ANALYSIS STRUCTURE

Keeping the P-3C fleet flying even this long was never planned.

—Stephen Trimble
Flightglobal

This chapter establishes the structure for this research analysis. With any DOD weapon systems, DOD Decision Support Systems provide the mechanism to allocate resources for system acquisition, and this mechanism starts with strategic planning and capability needs. The three principle decision support systems will be briefly discussed, focusing more on the guidance for service life extension of an existing weapon system in lieu of a replacement system. Furthermore, understanding the risks, trade-offs and best practices assist in this determination. Having established the scope of the analysis structure, the data and analysis of the P-3 Orion SLEP will follow in the next chapter.

A. DOD DECISION SUPPORT SYSTEMS

Every DOD weapon system is borne through the decision support systems. This system ensures that a weapon system meets a specific military requirement in terms of capability, receives funding through the federal budget, and is realized from concept to a tangible product within an acquisition management framework. Figure 2 depicts the three decision support systems for weapon system acquisition. According to Schwartz (2013), each support system is a process within itself and functions as follows:

- Joint Capabilities Integration and Development System (JCIDS) – identifies and generates requirements on what capabilities the military needs to execute its defined missions.
- Planning, Programming, Budgeting and Execution (PPBE) System – allocates resources and budgeting through DOD's proposed budget to include sourcing for all weapon system acquisition. DOD's proposed budget feeds into the President's budget, initiating the federal budget process. Ultimately, Congress authorizes and appropriates federal funding to acquire a weapon system.

- Defense Acquisition System (DAS) – manages the development and purchase of weapons and other military systems. (Schwartz, 2013, pp. 3-6)

These systems in combination should result in a weapon system that not only performs to required parameters, but also is obtained within cost constraints and fulfills a military capability requirement.

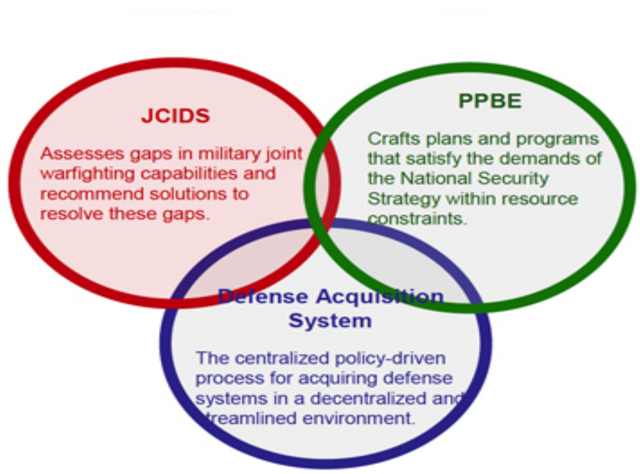

Figure 2. DOD Decision Support Systems (from Advanced Automation Corporation, n.d.)

Not all capability requirements result in acquisition of a weapon system. Schwartz (2013) illustrated that to enter in the DAS, a Materiel Development Decision review determines whether a new weapon system is needed to fulfill the requirement or a non-materiel solution will satisfy the requirement. A non-materiel solution could be altering defense or military strategy, eliminating the requirement, or modifying training to meet a requirement, for example. If the decision is for a new weapon system, funding must be obtained through the PPBE process (Schwartz, 2013).

B. REQUIREMENTS

Over time every weapon system eventually becomes a legacy system. As legacy systems age, components begin to fail. Unscheduled maintenance occurs more frequently requiring more resources to keep the system operationally available. As such,

funding requests increase annually in order to keep aged systems operational. While funding estimates get programmed in the PPBE process for system sustainment, budgeting indicates otherwise. According to Government Accountability Office (2010), "DOD's investments in legacy systems have generally been assigned lower priority in the budgeting process. As a result, many legacy aircraft systems are becoming increasingly difficult to maintain as parts needed to support key systems age and become obsolete" (Government Accountability Office [GAO], 2010, Highlights, para. 3). Aged systems face diminishing manufacturing sources, structural issues, and modernization efforts within their twenty-plus years of designed service life. Service life extension programs (SLEP) upgrade or replace system components but retain other components that may be asked to perform beyond their expected service life, encountering further obsolescence, structural fatigue, parts failure, and modernization efforts to meet military demands. Operating warfighters' systems beyond their expected service life, with or without SLEP, drive up sustainment costs. With DOD's decreased investment in legacy systems, legacy systems' performance suffers, reducing systems' availability to meet operational requirements.

At what O&S cost does the Navy decide to dispose of an aircraft weapon system? Maintenance and continuous modernization improvements cost may become too expensive to keep the aircraft operationally available. DOD's guidance states, "All acquisition programs respond to validated Capability Requirements" (Interim DoDI 5000.02, 2013, p. 5). In addition, an analysis of alternatives must provide trade-off considerations on O&S cost-estimation between "retiring the legacy systems and replacing them with new system or upgrading the legacy systems and extending the system service life, deferring the replacement of the new systems to a later date" (Office of the Secretary of Defense Cost Assessment and Program Evaluation [OSD CAPE], 2014, p. C-1). The decision to provide continued support to a legacy weapon system not only has to meet JCIDS' capability requirement, but also to satisfy the sensitivity analysis on the cost drivers between service life extension of a legacy system and a replacement system. Upon SLEP decision, affordability analysis follows to ensure that continued sustainment funding is programmed in the PPBE process.

C. AFFORDABILITY

O&S cost funding is subject to fiscal budget constraints. DOD Components therefore review their overall requirements and conduct resource planning in order to program their respective budget requests in the PPBE. To assist in this effort, the Components conduct an affordability analysis. This analysis not only prevents "continuing programs that cannot be supported within reasonable expectations for future budgets," but also "sets realistic program baselines to control life-cycle costs and help instill more cost-conscious management" (Interim DoDI 5000.02, 2013, p. 117). P-3 aircraft programs have to be managed within the confines of appropriated budget for the program based upon its O&S affordability cost estimate. The affordability cost estimation becomes an affordability cap once approved. However, if the affordability cap is exceeded, the Service Component must either "lower costs by adding cost control efforts to reduce program requirements or raise the cap by placing constraints on other programs, or terminate the program" (OSD CAPE, 2014, p. 3-7). The fiscal budget is a zero-sum process. Supporting cost overruns for one program reduces the funding for other programs. Continued poor cost management may even result in program termination.

Cost estimation that goes into the affordability analysis is a very complicated task. To support an aging airframe, the Navy needs to provide the cost estimate for both service life extension and modernization programs. The challenge in this process is to include and project potential costs that may be difficult to assess. For example, the Navy and the Air Force submitted a cost estimate to extend the service life of selected F/A-18s and F-16s. GAO (2012) found and reported that despite the comprehensive, well documented, and accurate cost estimate, these estimates were not credible because they "do not reflect some significant potential costs [in] how much the total costs will be and how they may increase if program quantities increase or additional work is required on some aircraft" (p. 10). More importantly, the lack of credible estimates "could hinder [the Service's] ability to assess realistic budgets and affordability" in order to make sound investment decisions (GAO, 2012, Highlights, para. 4). The P-3 similarly encountered this problem when the Navy funded the sustainment readiness program for

32 aircraft as described by Erwin (2000). Due to unanticipated corrosion on the aircraft, only 13 aircraft received SRP (Erwin, 2000). Funding for P-3 SLEP did not account for Zone 5 cracks at all since Zone 5 was unanticipated as a potential cost.

D. SUSTAINMENT

Requirements dictate the availability of a weapon system to execute an assigned mission. The acquisition of weapons systems serves to satisfy the capability requirements in terms of key performance parameters (KPP) and key system attributes (KSA). Defense Acquisition University (2012) defines KPP as "performance attributes of a system considered critical to the development of an effective military capability" and KSA as "system attributes considered most critical or essential for an effective military capability but not selected as Key Performance Parameters (KPPs)" (Hagan, 2012, pp. B100-B101). Because availability is such a critical criterion for an effective military capability as indicated in Interim DoDI 5000.02 (2013), sustainment for the weapon system is generally a KPP to ensure that both the materiel condition of the system's inventory is ready for tasking, and the system is capable to perform an assigned mission. Two KSAs are incorporated in the sustainment KPP: Reliability and O&S KSA. Reliability KSA ensures that the system will perform without failure for a specific interval and under specified conditions. O&S KSA promotes a balanced cost decision to meet both availability and reliability (Interim DoDI 5000.02, 2013).

Sustainment metrics assist in tracking and measuring the system's performance and cost, contributing to the sustainment KPP. The Navy uses mission capable rates to measure the materiel condition of the system to perform at least one of its assigned missions. Being able to perform all assigned missions is considered full mission capable (GAO, 2003). Utilization rates determine system's usage against its service life hours. An example of utilization rate is flight hours (GAO, 2005). The Navy uses this information and other metrics to determine fatigue-life expended (FLE) counting against structural-life limit of an aircraft and contributing towards a service life extension decision (Kim, Sheehy & Lenhardt, 2006).

E. SUMMARY

This chapter discusses the policy drivers on weapon systems. The weapon system must first fulfill a capability requirement, justifying its existence. Once the requirement is met, funding follows through the PPBE process. However, budgets fluctuate due to fiscal constraints and operational requirements. Through these changes, the weapon system must be affordable. To prioritize what the funding supports, sustainment metrics generated by KPPs and KSAs measure the availability and affordability of the weapon system in order to meet the warfighters' requirements.

III. DATA AND ANALYSIS

> *A successful program meets the sustainment performance requirements, remains affordable, and continues to seek cost reductions.*
>
> —Interim DoDI 5000.02

This chapter provides data and analysis on the P-3C aircraft. The Navy VAMOSC provided O&S cost data and captured maintenance and continuing improvement cost during the last two decades. Within this time frame, Naval Air Systems Command (NAVAIR) shows the number of aircraft in the fleet and the annual use of these aircraft. Lastly, GAO reports demonstrate the challenges of maintaining an aging aircraft's required mission capable rates.

A. O&S COST KEY SYSTEM ATTRIBUTES

P-3C Orion operating and support cost has increased steadily since 1994 (See Figure 3.1) after decommissioning all P-3B. Visibility And Management of Operating and Support Cost (VAMOSC) is the Navy's "management information system that collects and reports U.S. Navy historical weapon system operating and support (O&S) cost" (VAMOSC, n.d., About VAMOSC, para. 1). According to VAMOSC in 1994, the P-3C fiscal O&S cost was $1.3 billion in constant fiscal year 2013 dollars (FY13$) as compared to $1.5 billion in 2012. During this period, however, O&S cost did not grow gradually year over year; it peaked at a high of $1.95 billion in 2003. The aggregate difference from 1994 to 2012 totaled $5.1 billion above the 1994's O&S cost to sustain the aircraft. All funding is shown in FY 2013 constant dollars.

Several drivers pushed the O&S cost up. Generally, as the cumulative operating time increases beyond the useful life of the system, parts began to fail as the instantaneous failure rate increased exponentially. This wearout phase was captured in the bathtub effect (see Figure 4). As a result, more maintenance was required to keep the system operationally available. The P-3C maintenance cost did increase over time. Beyond the aircraft's service life, the components within the aircraft such as avionics and

engines failed more frequently. As a result, more organizational maintenance and support were required to maintain the aircraft. Intermediate maintenance also increased as parts reliability rate decreased. Depot maintenance was extensively used for SRP, SLEP and Zone 5 efforts, extending the airframe's useful life. Maintenance cost aggregated at $2.2 billion above 1994 levels, an average increase of 55% between 1994 and 2012.

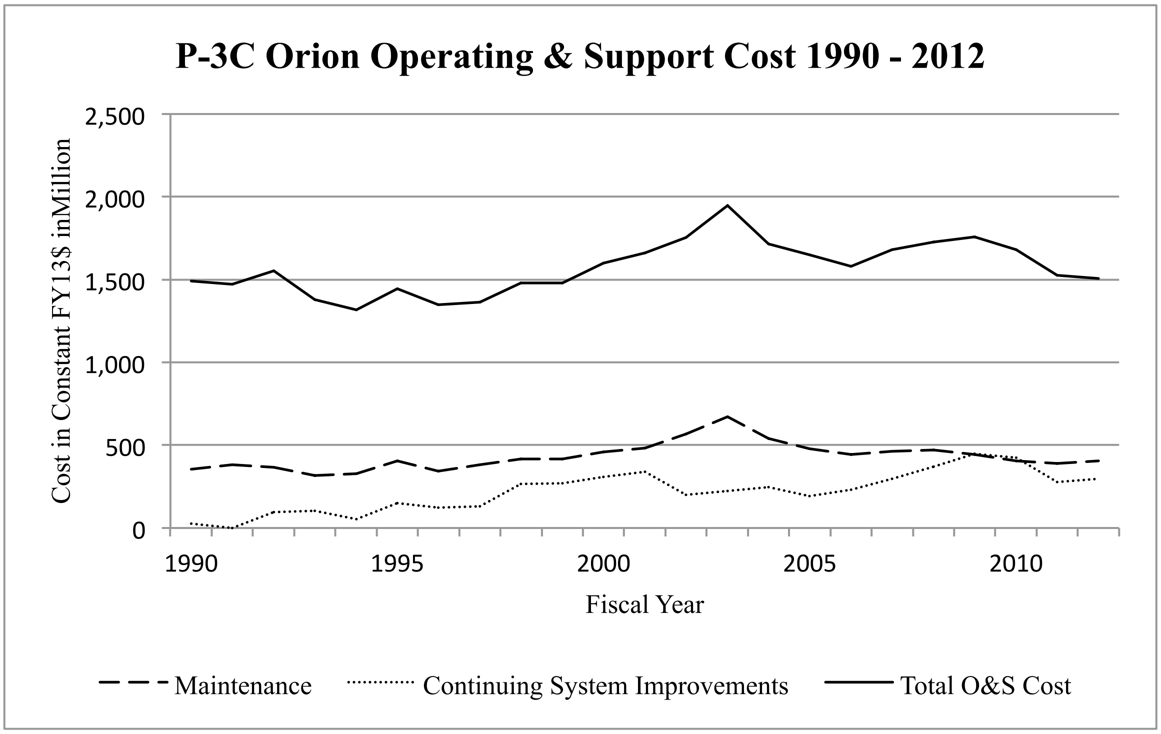

Figure 3. P-3C Orion Operating & Support Cost FY 1990 – 2012 (after VAMOSC, 2014)

Obsolescence and diminishing manufacturing sources and material shortages (DMSMS) occurred over time. DAU defines obsolescence as "the process or condition by which a piece of equipment becomes no longer useful, or a form and function no longer current, or available for production or repair," (Hagan, 2012, p. B-124) and DMSMS as "the loss, or impending loss, of manufacturers or suppliers of items, or raw materials, or software" (Defense Standardization Program Office, 2012, p. 1).

According to Defense Standardization Program Office (2012), as equipment becomes obsolete or a manufacturer discontinues production, reduced parts availability degrades systems capability. Furthermore, sustainment costs for obsolete items and diminished sources become unaffordable. Manufacturers may find continued production or support of obsolete items or low-demand items unprofitable. To manage affordable sustainment cost, continuous modernization is needed throughout the life of a system (Defense Standardization Program Office, 2012).

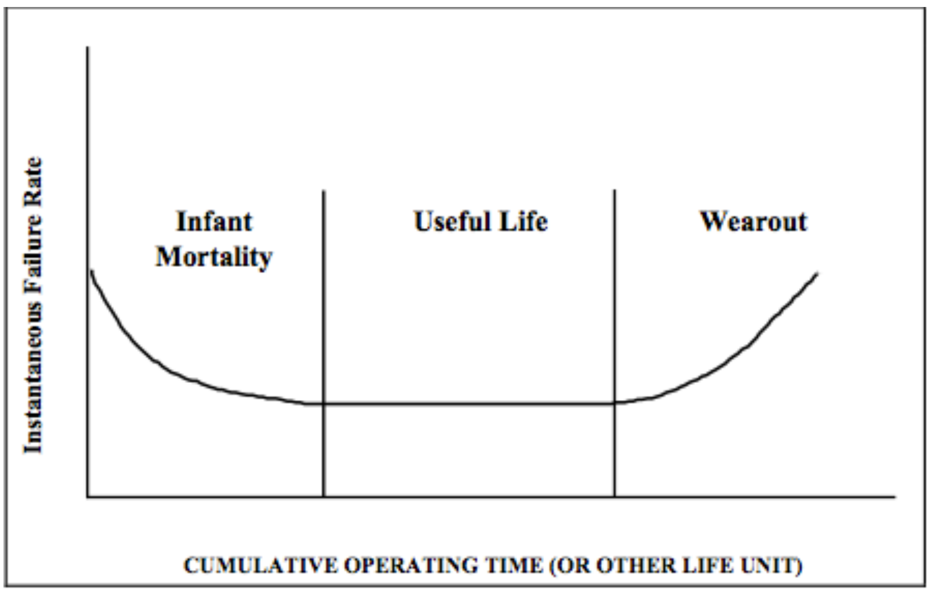

Figure 4. Bathtub Curve (from Rehg, 2008, p. 1-5)

For the P-3C Orion, continuing system improvements served as another driver of O&S cost. From 1994 to 2012, continuing system improvement costs increased significantly above 1994 improvement cost, aggregating at $3.8 billion during this period (see Figure 3). These improvements included both software maintenance and modifications and hardware modifications and modernization. *Defense Industry Daily* (2003) described continuing system improvement category as BMUP aircraft, ASuW Improvement Program, and C4 for ASW, naming a few P-3C upgrades. In addition, acoustic suite technical refreshes to software and hardware and radio replacement were critical obsolescence updates (*Defense Industry Dail*y, 2003).

The number of P-3C aircraft has decreased steadily since 1995 (see Figure 5). Steady reduction was based on the Navy's assessment and planned effort to phase out non-economically feasible aircraft. From 2005 to 2014, the statement of the Honorable Sean J. Stackley, Assistant Secretary of the Navy (Research, Development and Acquisition); Vice Admiral Joseph P. Mulloy, Deputy Chief of Naval Operations for Integration of Capabilities and Resources; and Lieutenant General Kenneth J. Glueck, Deputy Commandant Combat Development and Integration and Commanding General, Marine Corps Combat Development Command before the Subcommittee on Seapower and Projection Forces of the House Armed Services Committee on Department of the Navy Seapower and Projection Forces Capabilities (2014) captured the P-3C state of affairs as follows:

> The P-3C aircraft is well beyond the original planned fatigue life of 7,500 hours for critical components, with an average airframe usage of over 18,000 hours. Since February 2005, 174 aircraft grounding bulletins have impacted 136 P-3 aircraft. In December 2007, the Navy's Fatigue Life Management Program determined that in addition to existing structural fatigue issues associated with the forward lower wing section (Zones 2-4), the lower aft wing surface (Zone 5) of P-3 aircraft showed fatigue damage beyond acceptable risk resulting in the grounding of 39 P-3 aircraft. As of February 2014, a total of 93 aircraft have been grounded for Zone 5 fatigue. P-3 groundings due to known material fatigue will continue for the remainder of the P-3 program, and unknown fatigue issues will continue to present persistent risk until P-8A transition is complete. To date, $1.3 billion has been invested in P-3 wing sustainment, which has improved the overall structural health of the P-3 fleet. As of February 2014, there are currently 84 P-3C mission aircraft available. Preserving funding for Zone 5 and outer wing installations is critical to sustaining the minimum number of P-3Cs and other special mission variants required to meet warfighting requirements. (Stackley, Mulloy & Glueck, 2014, p. 22)

Since deciding on SLEP in 2002, the Navy has spent $1.3 billion on wing sustainment alone.

B. RELIABILITY KEY SYSTEM ATTRIBUTES

1. Utilization Rate

O&S cost continued to increase as the number of operational P-3C aircraft decreased. The number of P-3C aircraft peaked in 1995 with 213 aircraft in the fleet (see

Figure 5). O&S cost in 1994 was $1.4 billion in constant FY13 dollars. In 2003, O&S cost almost peaked at $2 billion mark supporting 173 aircraft. In 2006, the number of aircraft reduced even further down to 100 aircraft, costing $1.5 billion in O&S. In 2012, there were 89 aircraft, costing $1.5 billion in O&S. The O&S cost remained constant despite the decrease in the number of aircraft in the inventory.

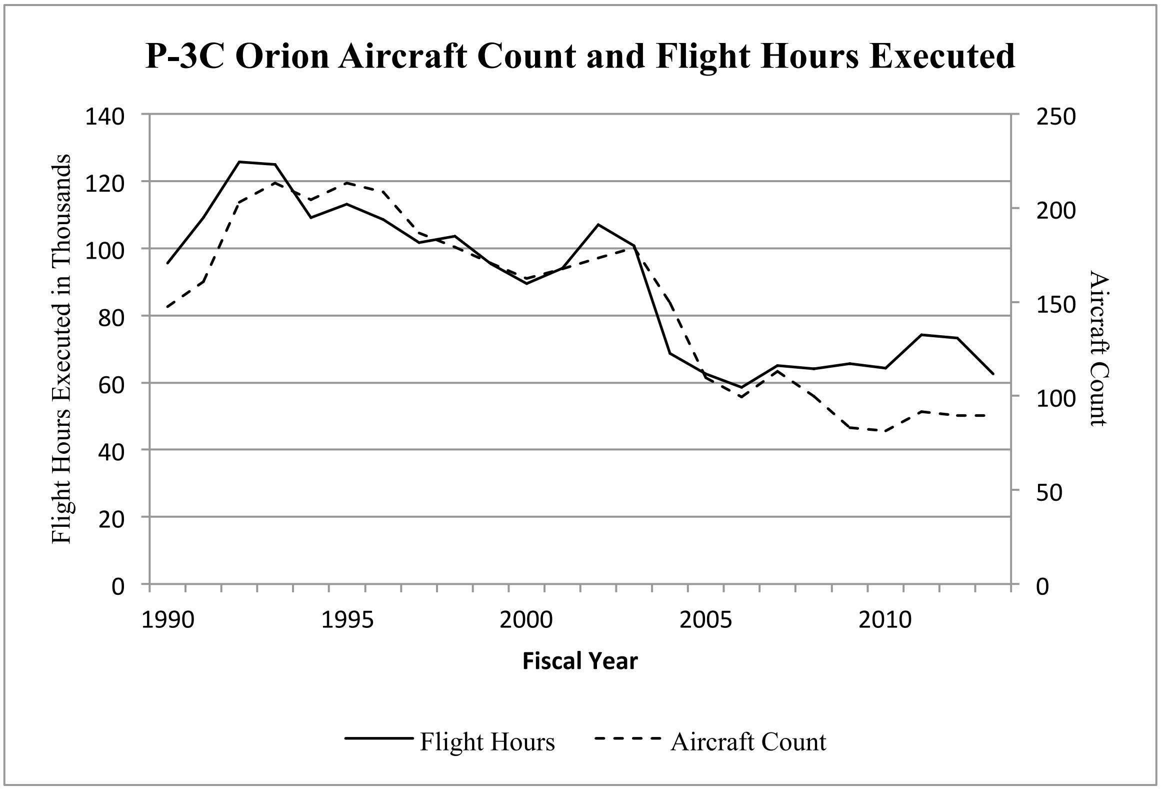

Figure 5. P-3C Orion Aircraft Count and Total Flight Hours Executed FY 1990 - 2013 (after NAVAIR, 2014)

As the number of aircraft decreased, flight hours also decreased from 1995 to 2007. Flight hours continued to average at 67 thousand hours per year from 2007 to 2013 despite the significant reduction of available P-3C aircraft in the fleet. Aircraft count in 2007 was at 113, dipping down to 81 in 2010, and finally, stabilizing at 89 in 2012. Flight hours, however, did not abate commensurate with aircraft reduction. Consequently, 81 aircraft executed the same amount of flight hours in 2010 that previously was flown on

113 aircraft in 2007. Somehow, P-3 executed the demanding flight hour requirement with fewer aircraft in the inventory.

The year 1994 may have been the beginning of the wearout phase, ending the useful life of the aircraft. From this point on, the aircraft demanded more O&S cost for frequent unscheduled maintenance as parts failed, for system upgrades to retain technology superiority against foreign threat, and for modernization efforts to combat components obsolescence and DMSMS. Ironically, aircraft inventory and aircraft usage steadily decreased after 1994 despite an increase in O&S cost. The sustainment cost per aircraft in its wearout phase significantly outpaced the cost in the useful life phase. The cost may have been justified to retain the required operational capability.

2. Mission Capable Rates

GAO (2003) found that the Navy uses mission capable (MC) and full mission capable (FMC) rates as metrics to determine aircraft availability. Mission capable rate was defined as a percentage of time that an aircraft can perform one of its assigned missions and FMC rate as when an aircraft can perform all of its assigned missions (GAO, 2003). NAVAIR (2009) explained that the P-3C aircraft could execute ASW, ASuW, and maritime patrol and reconnaissance missions, broadly categorizing the mission sets. To effectively execute each mission set requires multiple, complex sensor systems. Executing ASW, for example, requires the use of SASP system, Magnetic Anomaly Detection (MAD) system, Tactical Mission Software (TMS), and other associated systems to include communication system, navigation system, and radar system (NAVAIR, 2009). Conducting ASuW requires unique, complementing systems different from those of ASW except for common systems that can be used for both sets.

GAO conducted several reports on P-3C MC rates. The premise of GAO (2003) concerned DOD's availability goals, in particular the uncertainty in the goal setting "obscures basic perceptions of readiness and operational effectiveness, undermines congressional confidence in the basis for DOD's funding requests, and brings into question the appropriateness of those goals to the new defense strategy" (GAO, 2003, Highlights, para. 2). The disparity between goals and actual rate will not be discussed,

but the data used in the report was found as follows: At the time of the report, the average age of the P-3C aircraft was 24.5 years (GAO, 2003, p. 19). GAO found that the average MC rate was at 63 percent and FMC rate at 19 percent between 1998 and 2002 (see Figure 6). The P-3C can execute one of its missions 63 percent of the time, which was remarkable for aircraft at that age; however, to execute any of its assigned missions set, the P-3C was available only 19 percent of the time. While the report did not indicate which assigned mission had a high MC rate, switching ASW to ASuW mission, for example, from one day to the next may have not been feasible. Too many supportability problems contributed to the low FMC rate.

GAO listed possible factors that contributed to low MC/FMC rates. One factor was utilization rate where "more and more flying time is accrued over the passing years, problems due to materials and parts fatigue, corrosion, and obsolescence increase" (GAO, 2003, p. 18). This factor was expected, especially in an airframe that had neared the end of its service life. Another factor was spare part shortages from underestimates of demand. For a multi-mission aircraft, estimating needed parts to execute one of the three missions with multiple systems and sub-systems may have been a challenge. Furthermore, parts failed more quickly than anticipated due to increased operational tempos. Lastly, the P-3C aircraft consisted of complex systems that were very maintenance intensive, depending upon which missions and capabilities were required. At the time of this report, "Congressional Budget Office (CBO) estimates that spending for operations and maintenance for aircraft increases by 1 to 3 percent for every additional year of age," creating a funding concern for Congress (GAO, 2003, pp. 23-24).

GAO published an earlier report in 2005. At that time, GAO's purpose was to ensure that DOD "developed complete sustainment and modernization plans and identified funding needs for all priority equipment items [in order to] meet future requirements for defense capabilities" (GAO, 2005, p. Highlights). The GAO requested DOD to address the following P-3C deficiencies to the budget decision:

- The P-3Cs had maintenance issues resulting from the advancing ages and complexity of the equipment items. As a result, the aircraft consistently are missing their mission capable goals by a significant percentage.

- The Navy made structural inspections and repairs to ensure sufficient P-3 Orion aircraft to meet day-to-day requirements. Without some improvements to communications and defense systems, they will continue to degrade the ability of this aircraft to fulfill all of its missions.
- The aircraft required maintenance and technological upgrades in order to meet warfighting requirements. Obsolescence of the mission systems in the P-3 Orion aircraft over the long term needed to be addressed. (GAO, 2005, pp. 106–108)

In sum, age and overuse of the aircraft were key factors that contributed to the challenges in meeting MC goals.

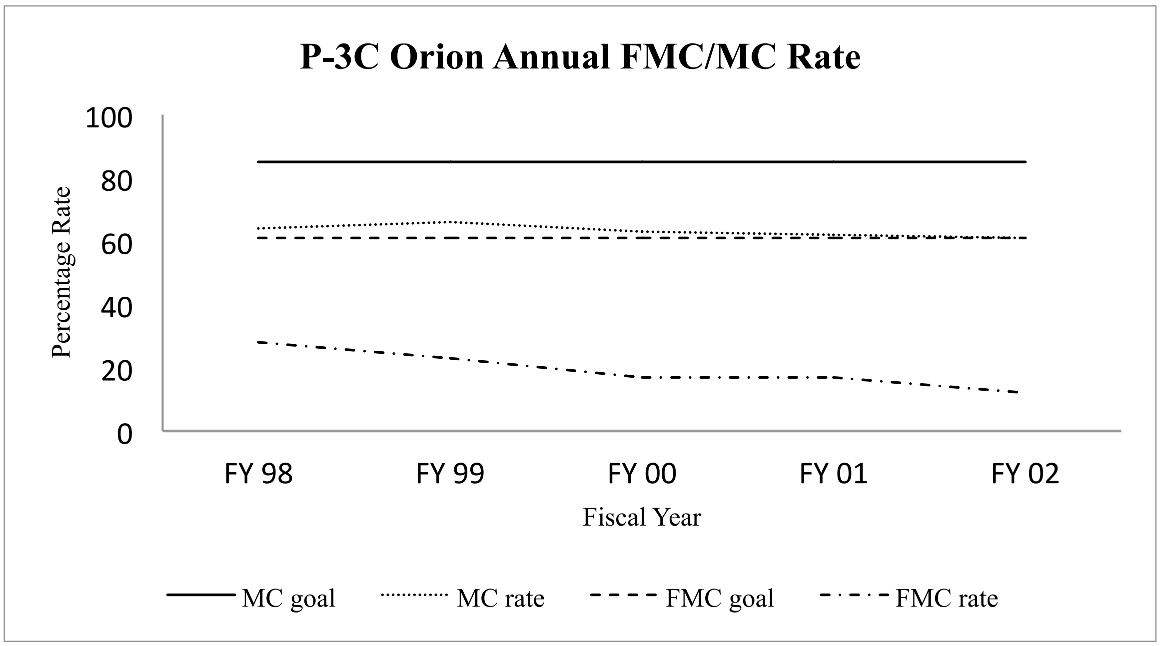

Figure 6. P-3C Orion Annual FMC/MC Rate (after GAO, 2003, pp. 46–47)

C. SUMMARY

P-3C sustainment indicated expected results from an aging platform. O&S cost increased to maintain failing parts and modernize the aircraft from obsolescence and DMSMS. SLEP and Zone 5 repairs consumed a considerable amount of resources as well. Despite a constant demand of missions and flight hours, aircraft count continued to decline. Flying more hours and missions with less aircraft contributed to higher parts failure rate, resulting in lower MC rate.

IV. FINDINGS

> When a SLEP is undertaken, it is assumed that a number of extra years of operation are added to an aircraft's life. Likewise, one might hope that a post-SLEP aircraft performs better, e.g., has greater availability levels or lower maintenance costs.
>
> —*Evaluating the Desirability of Navy F/A-18E/F Service Life Extension Progr*am

Reality may turn out completely different than what was assumed. The P-3C SLEP decision was made with best intentions to reduce total ownership cost while maintaining a warfighting capability. This chapter reviews the complexity of cost estimation for repair versus replace decision making followed by the Navy's aircraft structural-life management program. The findings on the P-3C sustainment after SLEP will be highlighted to include a brief summary in the end. Conclusions and recommendations follow in the next chapter.

A. SLEP DECISIONS

1. A Basis of Cost

Keating et al. (2010) provided a cost effectiveness assessment of SLEP for the U.S. Navy in 2010. This report responded to the Navy's request for decision-making criteria whether or not to SLEP F/A-18 E/F and C-2A aircraft. Many considerations went into this cost assessment to include the cost of the SLEP, the extra years and availability provided by the SLEP, the maintenance cost post-SLEP, and the cost of the new alternative aircraft. Keating et al. offered three cost methodologies for SLEP consideration: cost minimization, average cost per available year minimization and net benefit maximization. Using these methodologies, decision makers can weigh the cost option to get the biggest bang from SLEP in retaining warfighting capability, operational availability, and low maintenance cost for an extended period time as compared to a new aircraft. These cost methodologies provide trade space and "parameters" for the decision makers, using available information. However, the report continued to state, "Until a

SLEP is undertaken on a number of aircraft, there will be uncertainty as to the additional years provided by a SLEP, as well as post-SLEP availability and maintenance cost patterns" (Keating et al., 2010, p. 1). SLEP assessment provides decision makers insight into the potential of what SLEP can provide in extended years of capability and availability for an estimated cost. However, the outcome of available years, operational availability and maintenance cost post-SLEP cannot be reliably predicted in advance and can only be accurately determined after undergoing SLEP. (Keating et al., 2010)

2. A Basis of Remaining Fatigue Life

According to Kim, Sheehy & Lenhardt (2006), the Navy uses the safe-life approach to fatigue design to determine aircraft's design service life. Each landing, takeoff and maneuver stresses the aircraft's structure. The repeated stress over the aircraft's lifetime causes the structure to form fatigue cracks. Once a crack forms, it slowly degrades the aircraft's structural strength, and depending on aircraft usage, the crack can grow to the point of fracture or structural failure, where the part breaks. Knowing the point of failure is critical to apply the necessary safety measures prior to reaching structural failure (Kim et al., 2006).

Kim et al. (2006) explained that full-scale fatigue tests determine the mean time for a crack to initiate. Instead of using the normal or expected load, the Navy uses a worse case or severe load during the test looking for cracks. A crack is defined as 0.01 inch long. Once the fatigue life is determined, this value is divided by a life-reduction factor of two for variability in material properties and fatigue load. The outcome of the full-scale fatigue test and the life reduction factor determine a very conservative structural-life limit (Kim et al., 2006).

The Navy uses fatigue-life expended (FLE) metric on each aircraft type by tail number to track its structural-life limit. Kim et al. explained that FLE uses aircraft flight hours, takeoffs and landings to represent airframe and various fracture-critical components usage and then calculates accumulated fatigue damage. At 50-percent FLE, a SLAP is recommended to establish a case for SLEP, if required. Once an aircraft

reaches it structural-life limit or 100 percent FLE, the Navy can either decommission the aircraft or extend its structural life through SLEP (see Figure 7) (Kim et al., 2006).

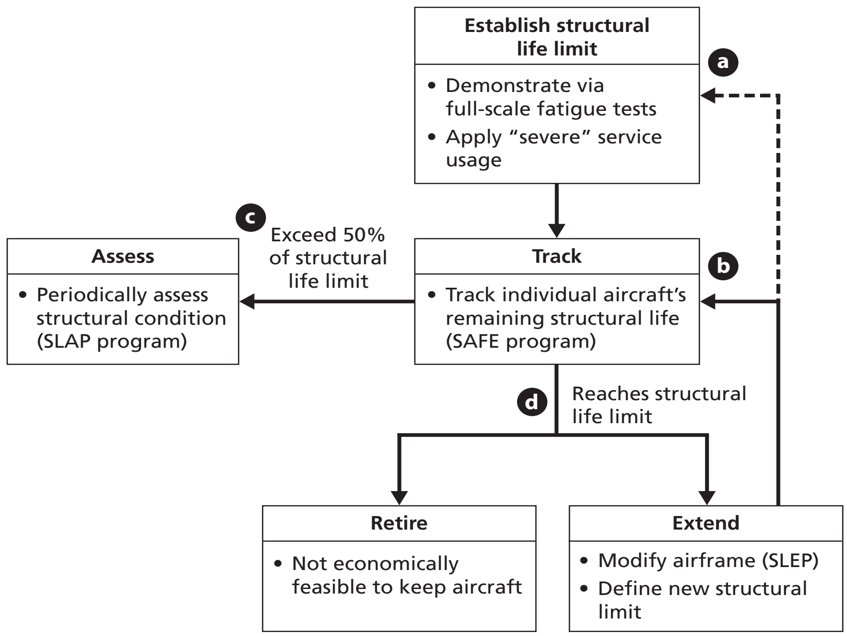

Figure 7. The U.S. Navy Aircraft Structural-Life Management Approach (from Kim, Sheehy & Lenhardt, 2006, p. 23)

The safe-life approach to fatigue design has its advantages. After testing or analysis, "the probability of failure is remote and no detectable cracks will exist during the determined structural-life limit" (Kim et al., 2006, p. 13). The Navy assumes that aircraft will be retired prior to seeing any cracks. As such, no safety inspection for fatigue cracks is required, eliminating the need for additional personnel and inspection equipment, especially in limited space aboard aircraft carriers. The Navy enjoys periods of maintenance-free operation without compromising safety of its aircraft (Kim et al, 2006).

B. P-3C SLEP

Structural life limit calculation for the P-3 was incorrect from the outset. The algorithm used for fatigue life assessment was dated, resulting in an erroneous structural-life limit calculation (Trimble, 2010). The Navy may have tracked inaccurate fatigue life

expended for two decades. Only when SLAP implementation introduced the full-scale fatigue testing was the true fatigue life of the airframe revealed: The actual fatigue life was well beyond the degradation predicted by the algorithm (*Defense Industry Daily*, 2013). With SLAP, corrective measures were also determined to remedy the known problems (Phan, 2003).

Kim et al. (2006) reported that structural inspection should be assessed through SLAP once the airframes exceed their 50% structural life limit. "This minimizes the risk of aircraft reaching its structural-life limits before a SLEP can be completed, thus avoiding flight restrictions or grounding" (p. 26). The P-3s, however, entered SLAP well beyond their 50% FLE. The P-3s had an operational, service life limit of 29.5 years (U.S. Navy, 1999). The P-3s went into SLAP with an average age of over 20 years, surpassing the 50% structural life limit (P-3 Orion Research Group, 2013). SLAP showed that some of the airframes were beyond the service life remaining where the Navy had to quickly reduce it P-3 fleet due to safety concerns (Global Security, 2011).

Defense Industry Daily (2013) reported that SLEP was intended to provide modifications and inspections in order to extend the airframe. The modifications addressed the corrosion areas as well as repairs to highly stressed areas. The inspections, such as the fatigue life management program, ensured that aircraft continued to fly safely by managing the existing cracks (*Defense Industry Daily*, 2013). Prior to SLEP, however, structural inspections were not required until airframes reached 50% of its expended fatigue life since the Navy adopted the safe-life fatigue approach (Kim et al., 2006). Upon commencement of structural inspections as a part of SLEP, airframe discrepancies were found to include unsafe cracks in the Zone 5 section of the wing (Global Security, 2011). Discovering Zone 5 cracks came unexpectedly as the Navy did not address this area in any of its repair programs, creating an un-programmed O&S maintenance cost (Warwick, 2007).

This research showed that O&S cost did increase significantly to sustain a platform approaching the end its service life. Service life extension applied to more than just the structural life of the aircraft. It involved all mission systems in the aircraft as well. As such, maintenance and modernization cost grew substantially as failure rates

occurred more frequently. With increased operations tempo, failure rates increased at a more rapid pace requiring more maintenance and system replacements. This phenomenon was well understood and captured by the bathtub curve.

P-3 SLEP case, however, was different. SLEP was designed to extend the airframe for a designated period. The P-3, however, went through multiple airframe repairs to include SRP, SLEP and Zone 5. As such, the cost of these combined efforts was more costly than had been experienced by other aircraft that went through one airframe extension program. Another difference from other aircraft SLEP experience was that the number of the P-3 aircraft did not remain constant. The aircraft count gradually declined as the O&S cost continued to grow. The cost of continuous system improvements also increased as the number of aircraft decreased. These combined factors made the P-3 analysis very costly.

Perhaps more research on structural life determination other than safe-life approach may better serve the P-3s. Kim et al. (2006) published that the Air Force prefers damage-tolerance approach to determine fatigue life. Unlike the Navy's maintenance-free inspection, damage-tolerance approach requires periodic inspection. Maintenance-free approach made sense for carrier-based aircraft due to limited hangar space, but land-based aircraft enjoyed a larger footprint in accordance with facilities construction code (Kim et al., 2006). Regarding the Navy's preference on tracking crack allowance over damage tolerance, NAVAIR P-3 IPT lead commented that initiating FLMP late in the P-3 service life cycle posed management challenges "unlike the Air Force which [did] it from the get-go" (Trimble, 2010, para. 7). Inspecting for cracks late in the service life cycle may have been a reactive approach as compared to a proactive approach in developing a sound database for decision making to pursue a successful SLEP.

Multiple approaches exist to sustain a weapon system, meeting requirements with available resources. A periodic business case analysis on cost and performance with these approaches may reveal efficiencies. Based on political trends and budget shortfalls, fiscal constraints will continue to impact DOD's programs. SLEP will most likely to be a preferred option over a new replacement system due to cost savings while fulfilling

capability requirement. Perhaps weapon system program management should seek efficiencies and practices in preparation for SLEP.

Despite cost savings, SLEP may not be the solution. The 21st Secretary of the Air Force stated "SLEP is expensive and puts updated systems on aging airframes" (Wynne, 2011, para. 35). The preferred method, according to Secretary Wynne, was acquiring new technology that has been built. This practice proved to be more cost effective since diverting money for SLEP diminishes the economy of scale on a replacement airframe. Furthermore, "pursuit of the best weaponry for both offense and defense is required for global engagement" (Wynne, 2011, para. 28). The U.S. needs to maintain a technology advantage to sustain its military superiority, and SLEP stifles any technology advantages.

Despite opposing views on SLEP, reduced funding and capacity may force the Services to pursue SLEP/modernization out of necessity. SLEP may offer the opportunity to skip a generation of a warfighting system—potentially saving a significant amount of money—if timed correctly. In any case, the P-3 SLEP offered many lessons learned as captured below:

- Sustaining an aircraft for two life cycles can be very expensive.
- Failure rates do increase as a system ages, resulting in ever-increasing O&S cost to keep the system operationally available. SLEP could have been a cost saver, if executed at the right time.
- Modernization efforts contribute to the O&S cost as well as keeping the system interoperable with other platforms. Modernization needs to be carefully reviewed through cost-benefit analysis (CBA) to determine the authenticity of the benefits and the realism of the cost estimates.
- Warfighting capability needs to be met. The P-3s may have been the only system available to perform the ISR missions during peacetime and wartime. As such, careful SLEP planning needs to be addressed while the SLEP option remains a viable option, especially when a warfighting replacement is not in sight.
- Above all else, proven algorithms should be used to calculate structural fatigue life. If the fatigue life algorithm had been correct, the P-3 outcome would have been very different in terms of cost and numbers of aircraft. SLEP aircraft could have been chosen on the basis estimated SLEP cost and expected future O&S cost.

SLEP served to bridge the capability gap until P-8A Poseidon entered the fleet (Erwin, 2000). Shortly after the P-3 entered SLEP, the Navy solicited a request for proposal for a replacement aircraft. Boeing won the contract with a 737-airplane derivative and promised to deliver initial operational capability in 2013, phasing out the P-3s by 2019 (Sherman, 2004). Bridging the gap required modernization efforts to address obsolescence and DMSMS. O&S costs increased significantly. The cost drivers included SLEP, Zone 5 repairs and improvement programs. Even with the significant expenditures, aged systems continued to fail, and mission capable rates suffered.

Cost savings had to be compared with at least one alternative, the P-8 Poseidon as a replacement aircraft. A P-3 unit cost was 36 million FY87 dollars or approximately 73 million in FY13 dollars (NAVAIR, 2009). A unit cost of a P-8 Poseidon was approximately 220 million FY13 dollars (NAVAIR, 2014). P-3 wing sustainment to date cost 1.3 billion FY13 dollars (Stackley et al., 2014). From 2007 to 2012, maintenance and continuous improvements cost 4.7 and 2.1 billion FY13 dollars, respectively (VAMOSC, 2014). These additional expenditures could buy a fleet of 43 P-8 Poseidon well ahead of the current 2019 IOC.

C. SUMMARY

Many considerations go into a SLEP decision. The cost analysis is a comparison between the SLEP of a legacy system to the cost of a replacement system with the goals of obtaining the best value, minimizing of sustainment cost and meeting wartime operational necessities. Determining how much fatigue life remaining also contributes to the SLEP decision. The Navy prefers the safe-life approach where periodic structural inspection is not required. However, when half of the structure-life limit is breached, SLAP assesses the remaining fatigue life expended and recommends structural repairs and periodic structural inspections for SLEP. Furthermore, the arrival of a replacement aircraft determines the level of effort to maintain a legacy system. These considerations went into P-3 SLEP decision. One of the unanticipated outcomes of P-3 SLEP was the discovery of Zone 5 cracks that undermined and invalidated the cost estimates and perhaps the SLEP decision.

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V. CONCLUSIONS AND RECOMMENDATIONS

The longer you can look back, the farther you can look forward.

—Winston Churchill

A. CONCLUSIONS

DOD provided a broad guidance for SLEP decision. According to DAU's IPS Element (2011), it stated,

> Service life extension planning involves a consolidated approach which reconciles force structure requirements and force planning, inventory projections, usage forecasts, threat assessments, planning factors, and cost, schedule and performance status of current programs and in-service fleets. (p. 196)

Beyond this overarching guidance for service life extension, Services delved with due diligence into each of these considerations. DOD has provided ample guidance in these respective areas. Each of the Services has also developed their own guidance in policies, instructions and guidebooks. The SLEP decision, however, rests with the respective Service based upon their findings and overall objectives, bounded by applicable constraints (Interim DoDI 5000.02). Sustaining a SLEP system like the P-3s appeared to have more challenges than benefits, as described below.

The P-3s appeared to be poor a candidate for service life extension due to the following reasons:

- Sustained readiness program (SRP) failed to address the airframe issues in 1994 (U.S. Navy, 1999). Erwin (2000) indicated that SRP found excessive corrosion in the airframe. Only 13 of 221 received SRP. As such, corrosion needed to be addressed for the remaining fleet as well as other structural concerns identified in SRP (Erwin, 2000).
- The P-3s entered service life assessment program (SLAP) well beyond the recommended 50% fatigue-life expended (FLE). Kim et al. (2006) found that airframes entering SLAP at 50% FLE offered a better assessment on the remaining structural life for SLEP consideration. With a designed service life of 29.5 years, the P-3s entered SLAP with over 20 years on the airframe (U.S. Navy, 1999; P-3 Orion Research Group, 2013).
- The P-3s' service life remaining was questionable. The dated algorithm

used by Lockheed during SLAP inaccurately assessed remaining service life of the aircraft (Trimble, 2010). The structural-life test showed the airframe had less life than expected, resulting in an expeditious retirement of many P-3 aircraft (Global Security, 2011). In addition, Kim et al. (2011) illustrated that Navy used the safe-life structural approach. As such, the P-3s did not receive periodic structural inspections until post-SLAP, which yielded the structural condition of the airframe an unknown factor.

- The P-3s did not have sufficient service life remaining for SLEP. After SLAP, engineers recommended that many P-3s had less service life than expected (Global Security, 2011). The results showed that it was perhaps more cost effective to reduce the number of aircraft and to have a limited number of aircraft go through SLEP.
- SLAP did not address Zone 5. SLAP conducted full-scale fatigue test (FSFT) and provided remedies for the airframe issues (Phan, 2003). SLAP, however, did not address the Zone 5 section of the wing. As a result, intolerable cracks were discovered in this section that grounded the already limited number of P-3 aircraft (*Defense Industry Daily*, 2013). The intent of SLAP had been to prevent the unintended flight grounding of aircraft (Kim et al., 2011).

The reasons above indicated that the P-3s were already experiencing structural issues that required substantial refurbishment in order to keep the aircraft operationally available.

Despite the P-3s being a poor candidate for SLEP, the aircraft fulfilled a mission requirement. Mission requirement drove the need for service life extension for the following reasons:

- The P-3s had relatively long range and on station endurance. The long-endurance capability made the P-3s a formidable asset for surveillance of the battle space (NAVAIR, 2009).
- The P-3s were capable of executing the new mission. Despite being an old platform design for ASW missions, the P-3s expanded its mission set to include ASuW and overland missions, supporting regional defense strategy (Deagle, 2014; Cheney, 1993).
- The P-3s had a trend of perceived low-cost sustainment. VAMOSC (2014) indicated that the operating and support cost of the P-3s were relatively steady and predictable prior to the SLEP decision.
- The P-3s were needed to bridge the capability requirement until their replacement aircraft entered the fleet. With the P-3s being a multi-mission aircraft, theater and fleet commanders required a constant forward-deployed presence until the P-8s relieved the P-3s of its duties (Deagle, 2014).

The P-3s fulfilled a capability requirement that theater commanders wanted.

The P-3s met the warfighters' requirements. As such, the decision to SLEP the P-3s was justified in spite of telltale signs of the P-3s' structural condition. Since deciding on SLEP,

- Sustainment cost increased due to maintenance and continuous improvement requirements (VAMOSC, 2014).
- Performance declined as indicated by low MC/FMC rates, increased failure rates, and grounding of aircraft due to the discovery of Zone 5 cracks (GAO, 2003; GAO, 2005; Trimble, 2010).
- The Navy did not garner the full potential benefits of SLEP. SLEP promised an extension of another lifetime (Erwin, 2000). That promised fell short as Zone 5 crippled the P-3 fleet.

Meeting the warfighters' requirements resulted in an increased pressure on cost, schedule and performance in order to sustain the aircraft.

B. RECOMMENDATIONS

The P-3 SLEP provided an invaluable insight into the service life extension process. Based on this research, the recommendations for SLEP decision-making are as follows:

- Validate accuracy of algorithm on full-scale fatigue test. The accuracy of the algorithm used for any tests establishes a sound fatigue-life baseline, minimizing safety, cost, and performance risks.
- Consider damage-tolerance structural life approach. Damage-tolerance approach requires periodic airframe inspection, which aids in accurate determination of structural-life remaining for the longevity of the airframe.
- Ensure SLAP thoroughness. SLAP thoroughness assesses all points on the airframe. As a result, the findings on the SLAP not only minimize any airframe risks during SLEP, but also provide performance predictability during the extended life that SLEP offers.
- Adhere to SLAP schedule at 50% FLE. The safe-life approach to structural determination has its advantages in that no periodic airframe inspection is required during the airframe's calculated structural-life limit. Adhering to SLAP assessment at 50% FLE ensures the safety of the aircraft as well as the SLEP potential of the airframe.
- Realize SLEP risks on an old platform. An older platform poses an inherently higher risk of failure on the airframe and on the mission

systems. While the benefits of SLEP extend the service life at a reduced cost, updated and new mission systems will most likely outlive the platform's service life. Weighing the return on investment of a new mission system in an old airframe may offer significant trade-offs.

- Consider a holistic decision making of SLEP based on performance, sustainment cost and risks as compared to a replacement platform. Perhaps conducting a business case analysis, cost analysis, sensitivity analysis, performance baseline, mission execution longevity, safety and overall sustainment cost and total ownership cost may aid in the decision making. Nonetheless, expect inherent risks on a legacy system.

The list stated above was not all-inclusive but to serve as the highlights gleaned from the P-3 SLEP.

VI. SUMMARY

One of the things we have to do is to go through program-by-program and try to understand exactly what decisions were made and why they were made.

—Frank Kendall,
Under Secretary of Defense Acquisition, Technology and Logistics

Deciding to execute a service life extension on a program is difficult because the analysis must be multi-faceted. With a major weapon system, SLEP impacts the family of systems as well. The P-3 SLEP confirmed the sustainment challenges of a system that has been in the service for over four decades. Perhaps a part of that challenge was that the P-3 was not intended to undergo SLEP, but it did. From a cost and performance perspective, the P-3 required more resources in order to sustain its performance, but that was to be expected. Once the airframe reached its structural-life limit, two options existed: Retire or extend. The decision-making process leading up to the determination for extension such as SLEP needed to be known and understood and the assumptions overtly stated. This way, risk identification and management could be better implemented.

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